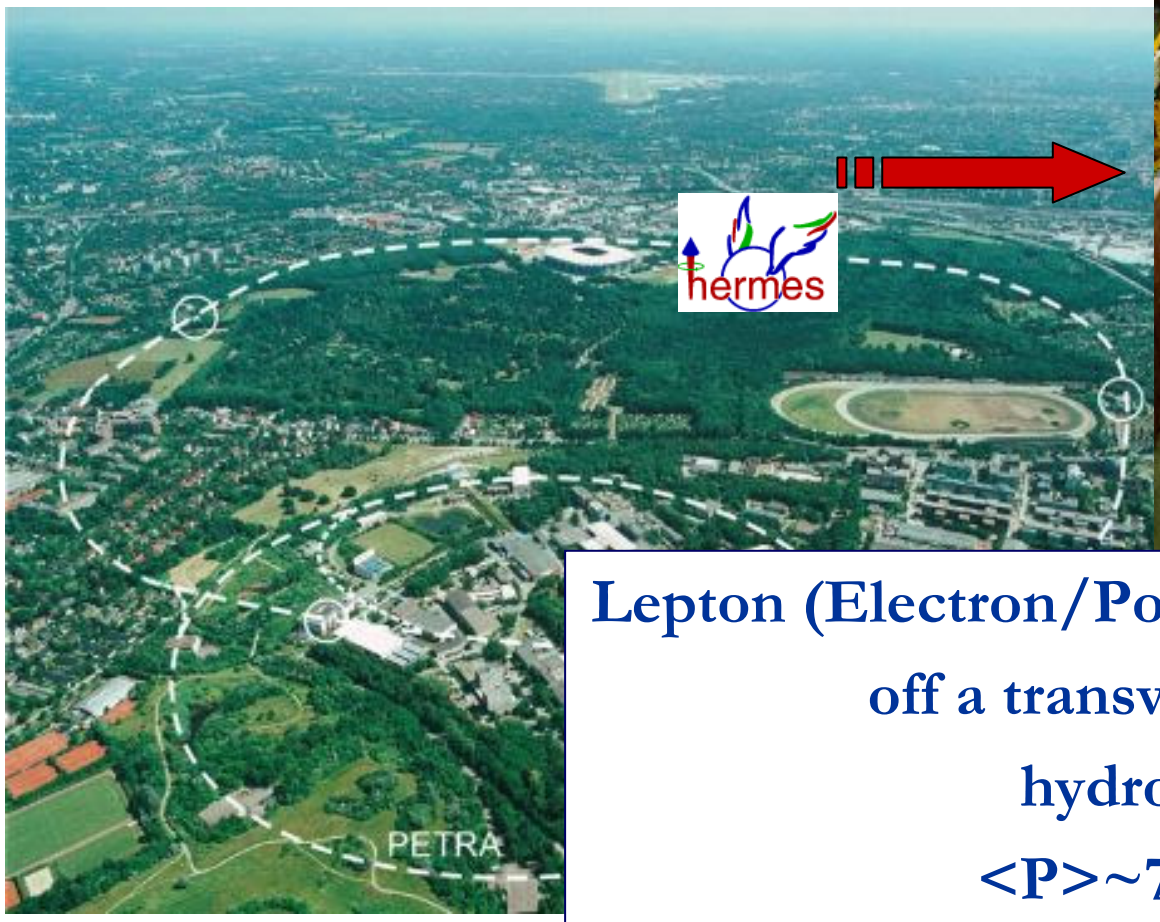
measurements of the transverse spin structure

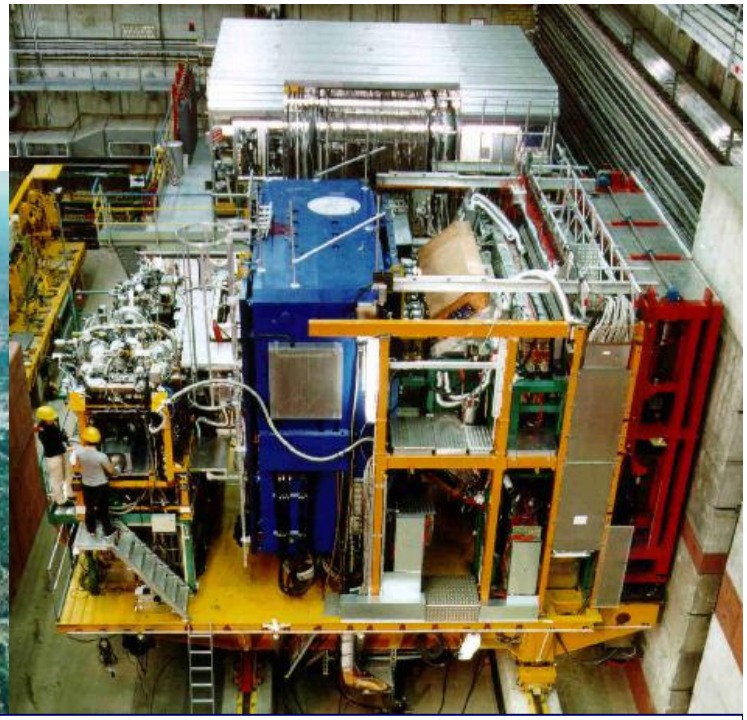
Francesca Giordano
INFN sez. Ferrara
Università degli studi di Ferrara

HERa MEasurement of Spin

HERA storage ring @ DESY

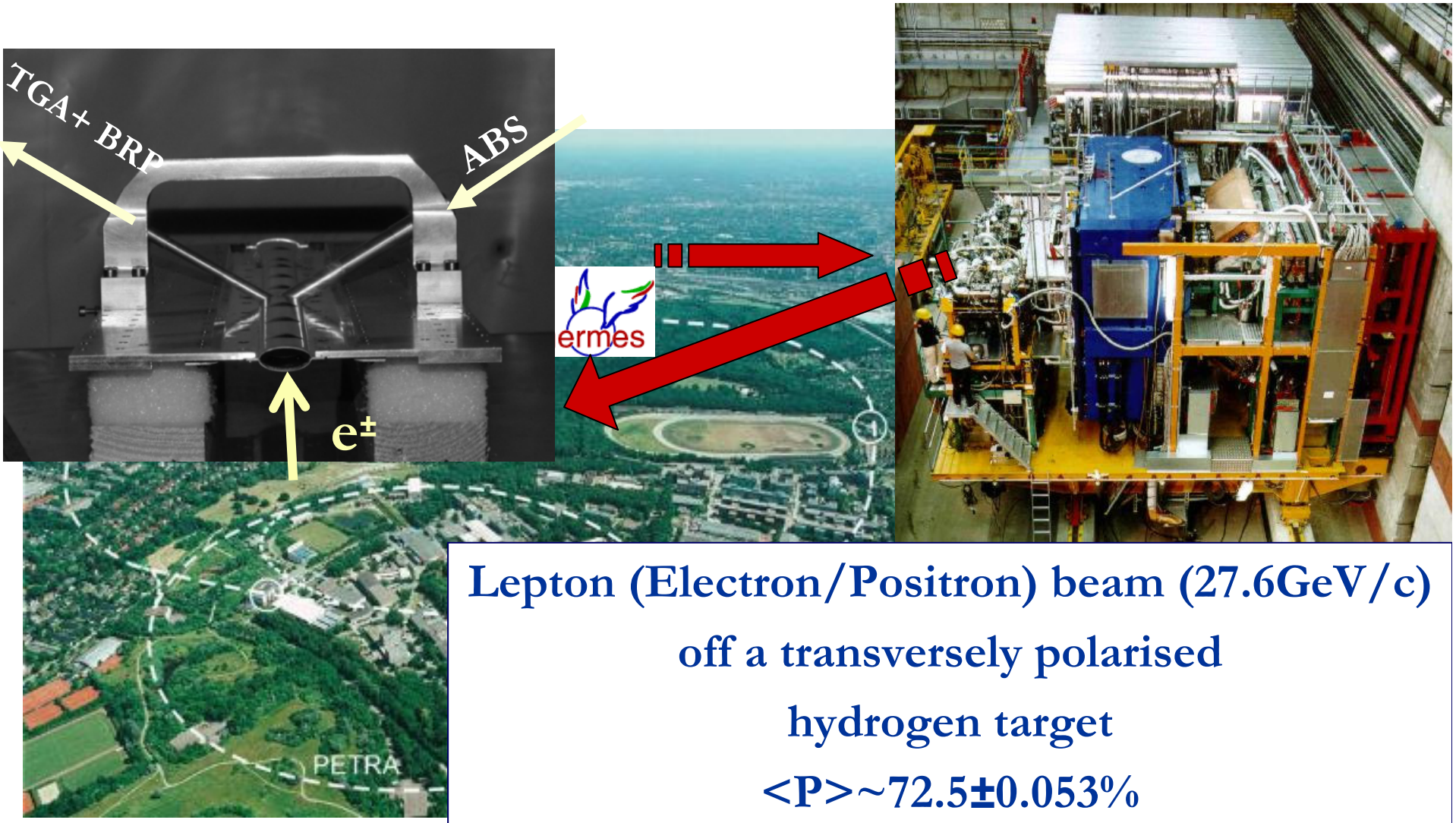
HERa MEasurement of Spin





Lepton (Electron/Positron) beam (27.6GeV/c)
off a transversely polarised
hydrogen target
<P>~72.5±0.053%

HERa MEasurement of Spin



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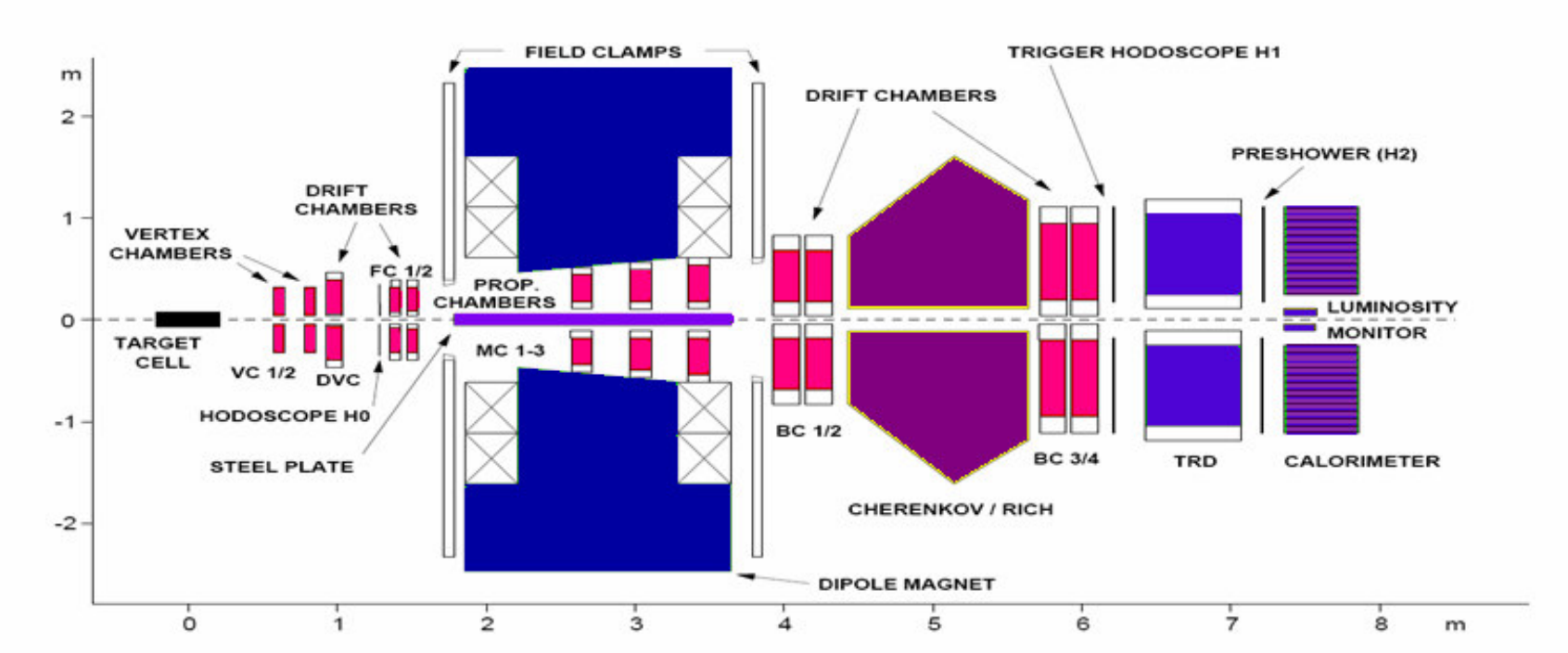
HERMES spectrometer

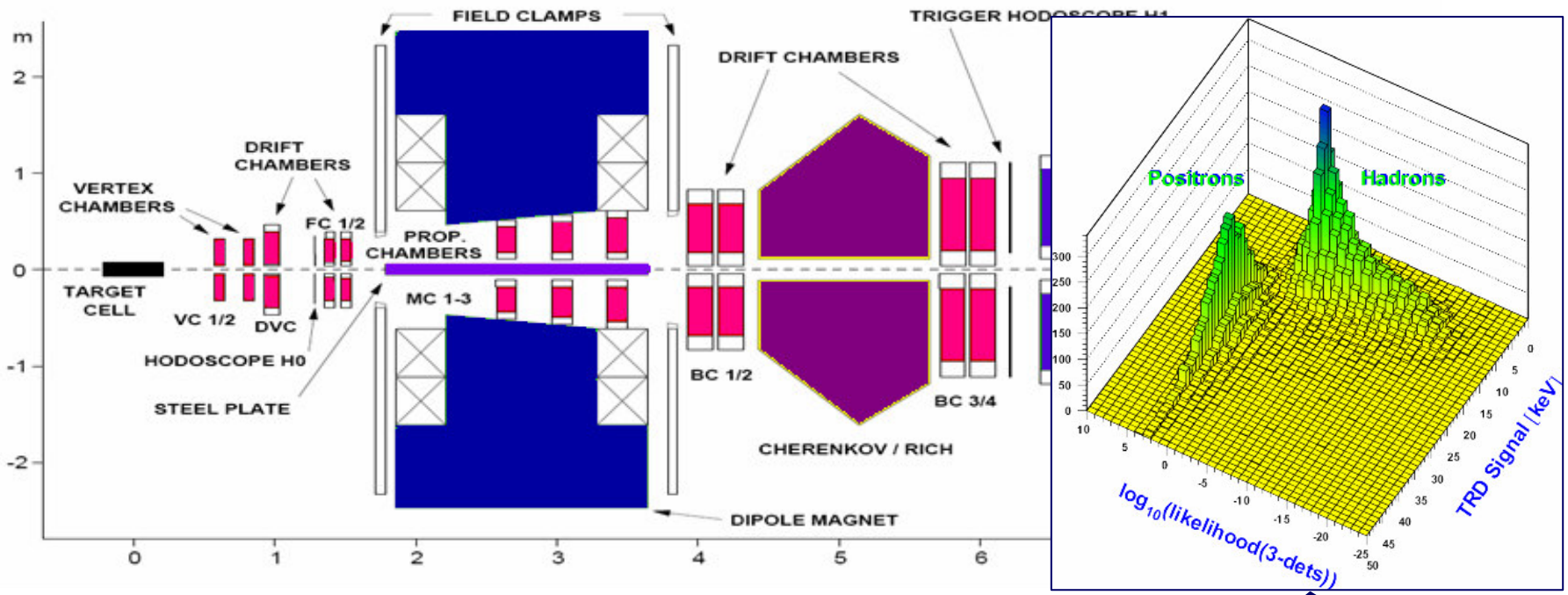


Resolution: $\Delta p/p \sim$ 1-2% $\Delta\theta <\sim$0.6 mrad

Electron-hadron separation efficiency ~ 98-99%

Hadron identification with dual-radiator RICH

HERMES spectrometer



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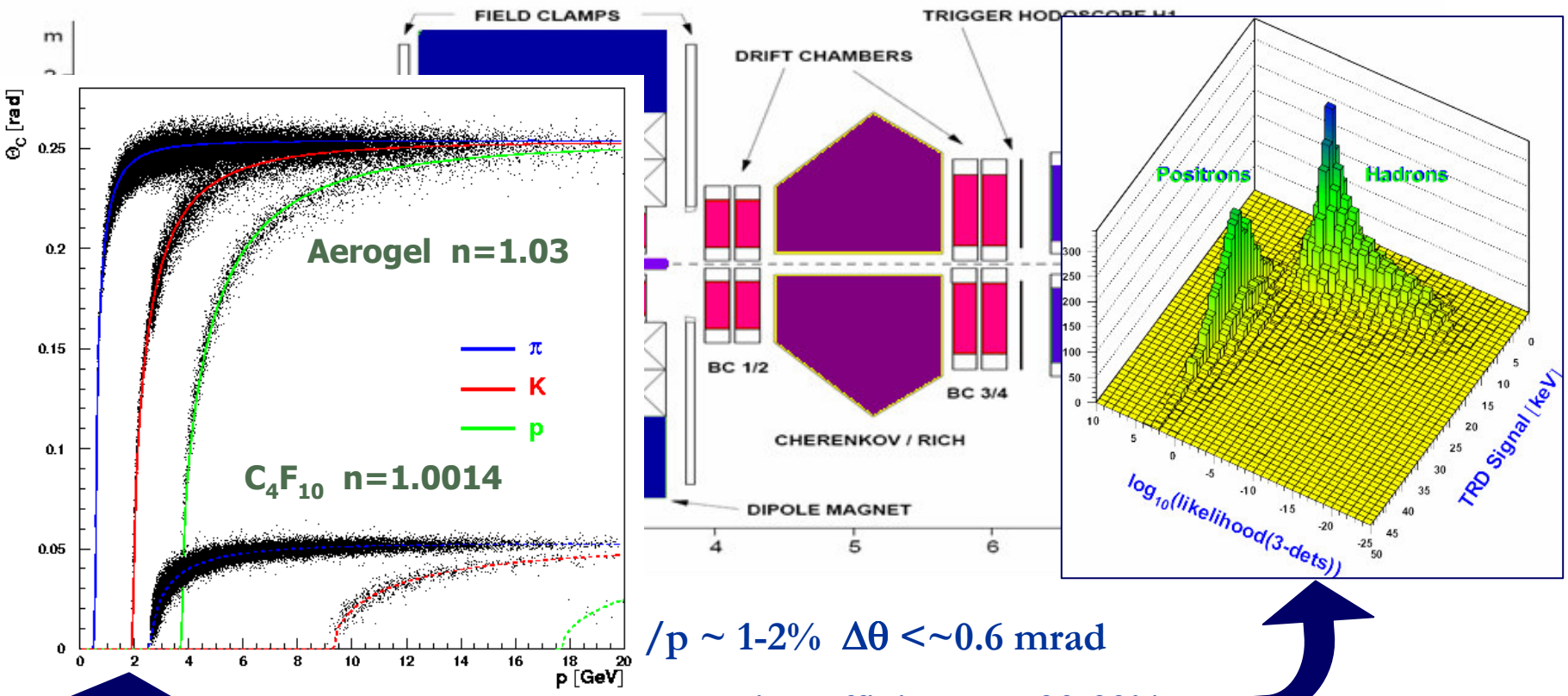
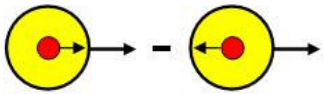
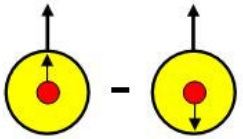


/p ~ 1-2% Δθ <~0.6 mrad

Electron-hadron separation efficiency ~ 98-99%

Hadron identification with dual-radiator RICH

Leading twist Distribution Functions

		quark		
		U	**L**	**T**
nucleon	**U**	q 		
	L		Δq 	
	T			δq 

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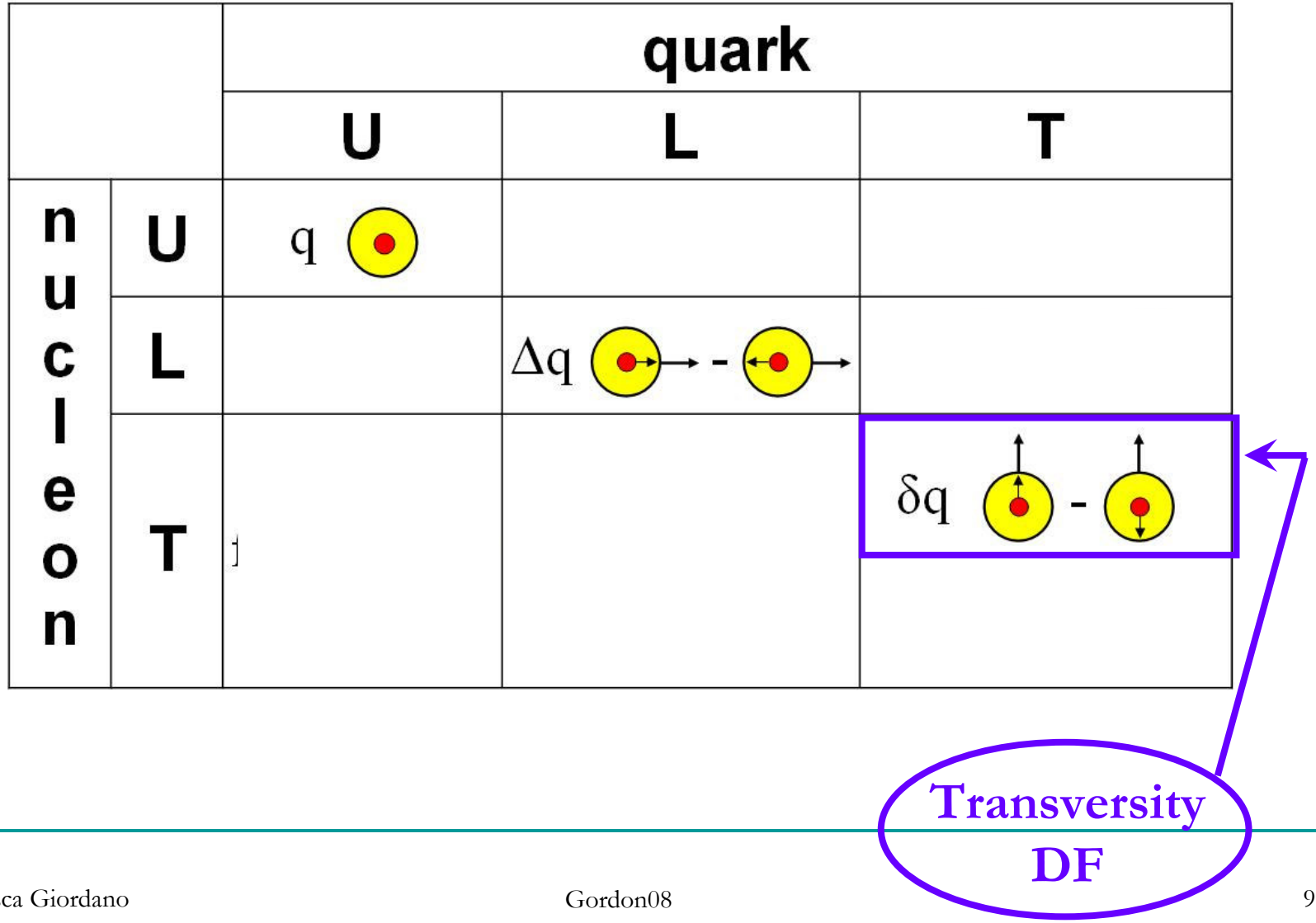
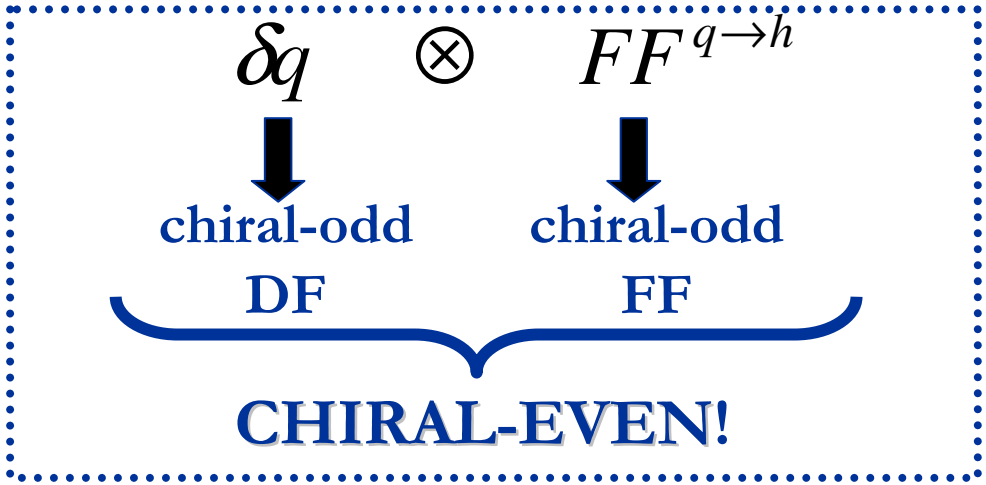


Transversity

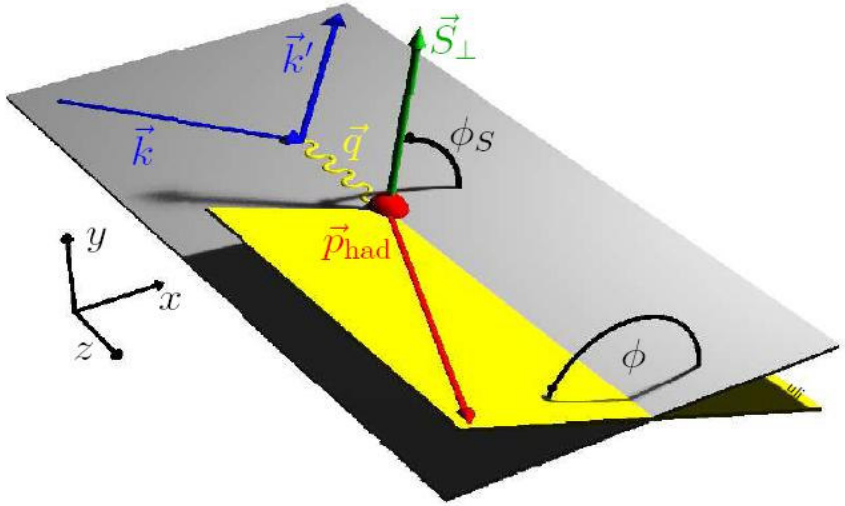
As Transversity is a **chiral-odd** function it can be probed only in conjuction with another chiral-odd function

In **S**emi **I**nclusive **D**eep **I**nelastic **S**cattering it is coupled to a chiral-odd **F**ragmentation **F**unction



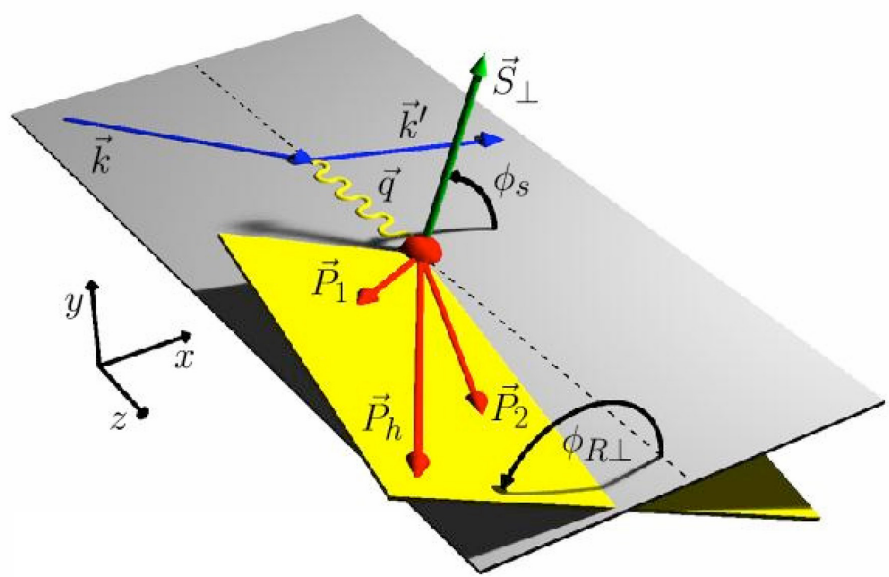
Semi Inclusive Deep Inelastic Scattering

1-hadron production



$$\sigma_{UT} \propto S_T \sin(\phi_h + \phi_S) \sum_q e_q^2 \, I\left[\frac{k_T \cdot \hat{P}_{h\perp}}{M} \delta q \cdot H_{1,q}^{\perp}\right]$$

2-hadron production



$$\sigma_{UT} \propto |S_T| \sin\theta \sin(\phi_{R\perp} + \phi_S) \sum_q e_q^2 \, \delta q \cdot H_{1,q}^{\sphericalangle}$$

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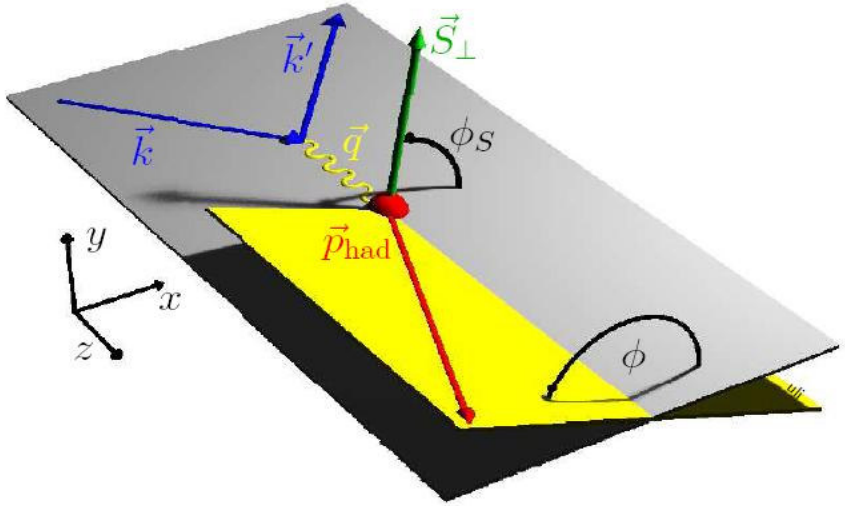

Collins Fragmentation Function

$$\sigma_{UT} \propto S_T \sin(\phi+\phi_S)\sum_q e_q^2 \; I\left[\frac{k_T \cdot \hat{P}_{h\perp}}{M}\,\delta q \cdot H_{1,q}^{\perp}\right]$$

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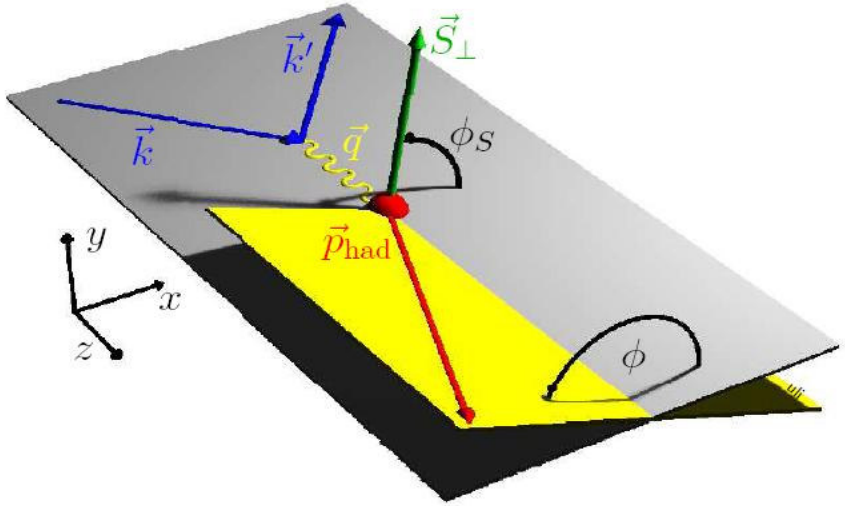

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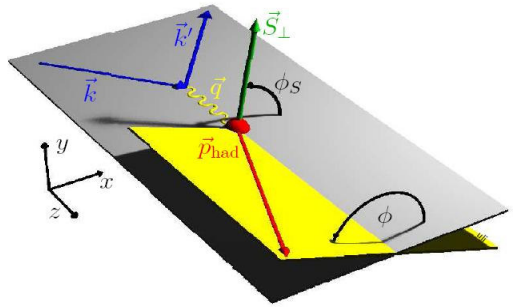
Collins signature

1-hadron production

$$A_{UT}^{h} = \frac{\sigma_h^{\Downarrow} - \sigma_h^{\Uparrow}}{\sigma_h^{\Downarrow} + \sigma_h^{\Uparrow}}$$



$$A_{UT}^{h} \propto 2\left|S_T\right|\sin\left(\varphi+\varphi_S\right)\frac{\sum_q e_q^2\ I[\frac{(\vec{k}_T\cdot\hat{P}_{h\perp})}{M_h}\delta q(x,p_T^2)H_1^{\perp q}(z,k_T^2)]}{A(y)\sum_q e_q^2 q(x,p_T^2)D_1^q(z,k_T^2)}$$

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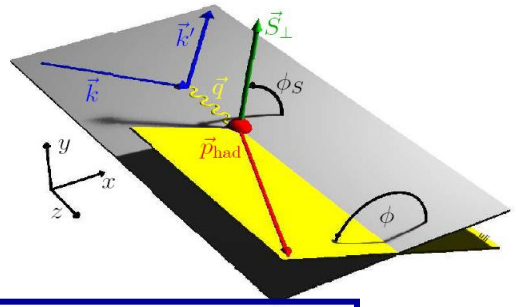

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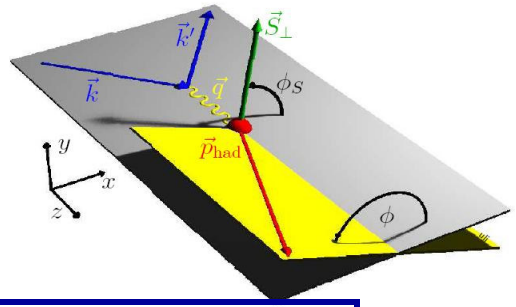

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Collins signature

$$+ 2|S_T| \sin(\varphi - \varphi_S) \frac{\sum_q e_q^2 \, I[\frac{(\vec{p}_T \cdot \hat{P}_{h\perp})}{M} f_{1T}^{\perp q}(x, k_T^2) D_1^q(z, k_T^2)]}{A(y) \sum_q e_q^2 q(x, k_T^2) D_1^q(z, k_T^2)}$$

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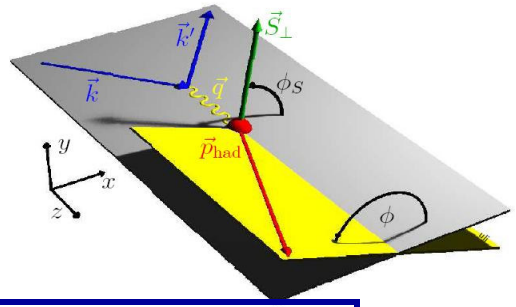

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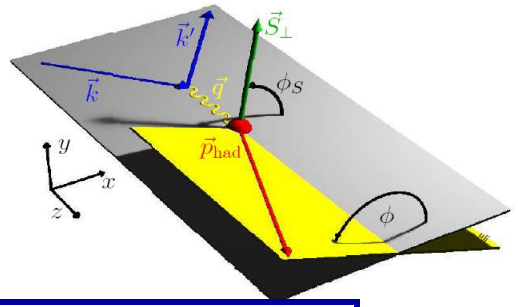

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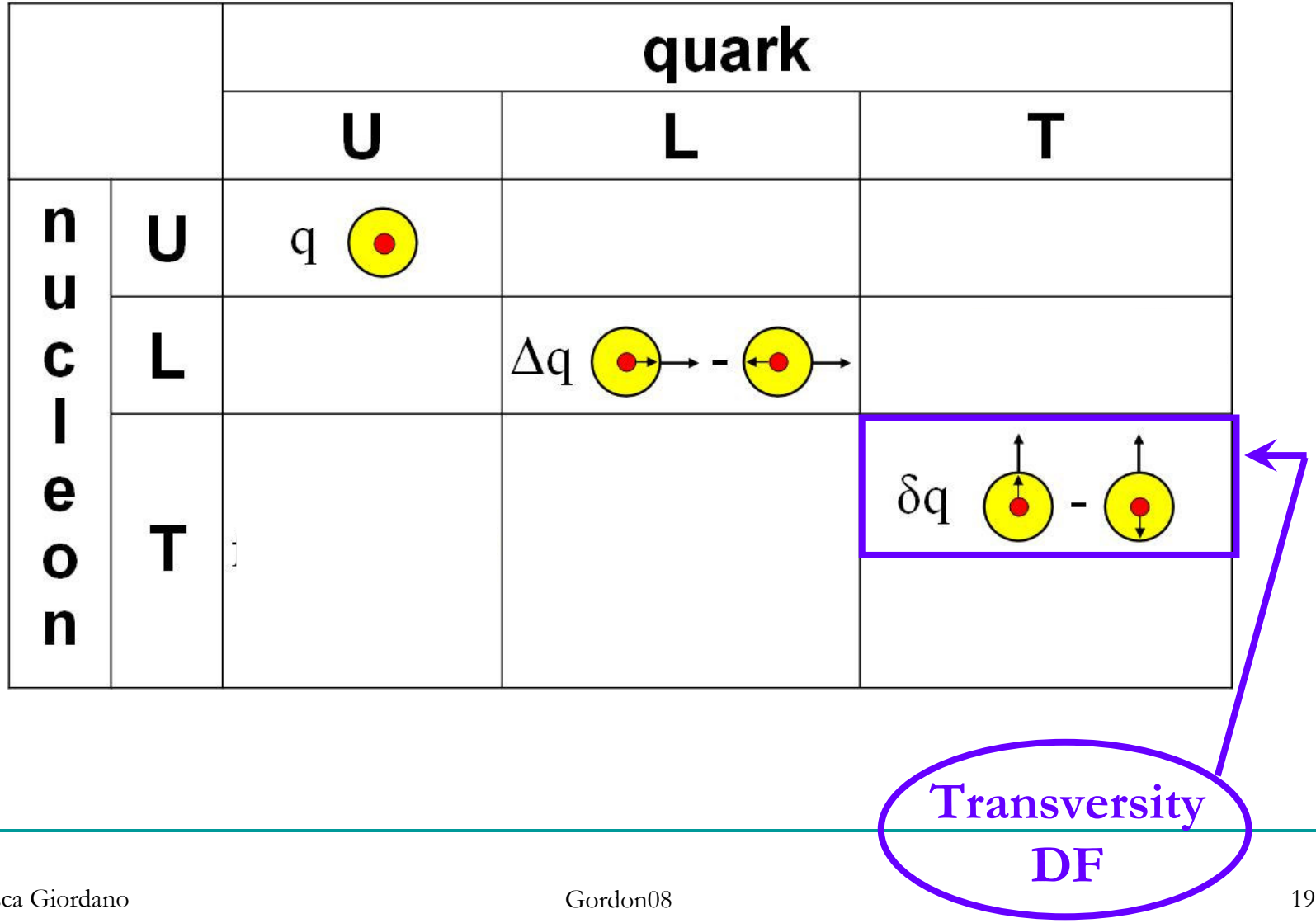
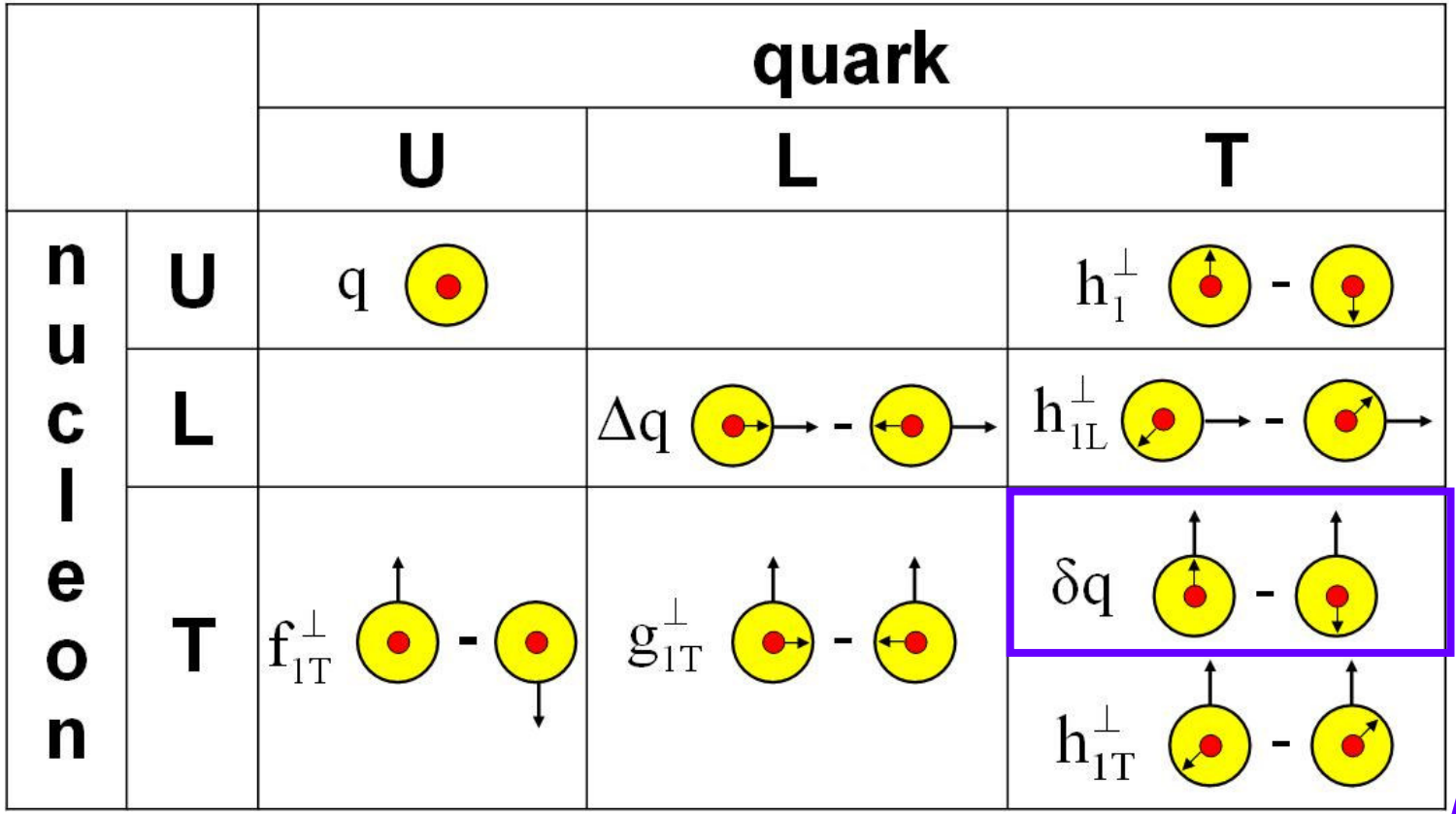
Sivers signature

Leading twist Distribution Functions



The TMD Distribution Functions



Transversity DF

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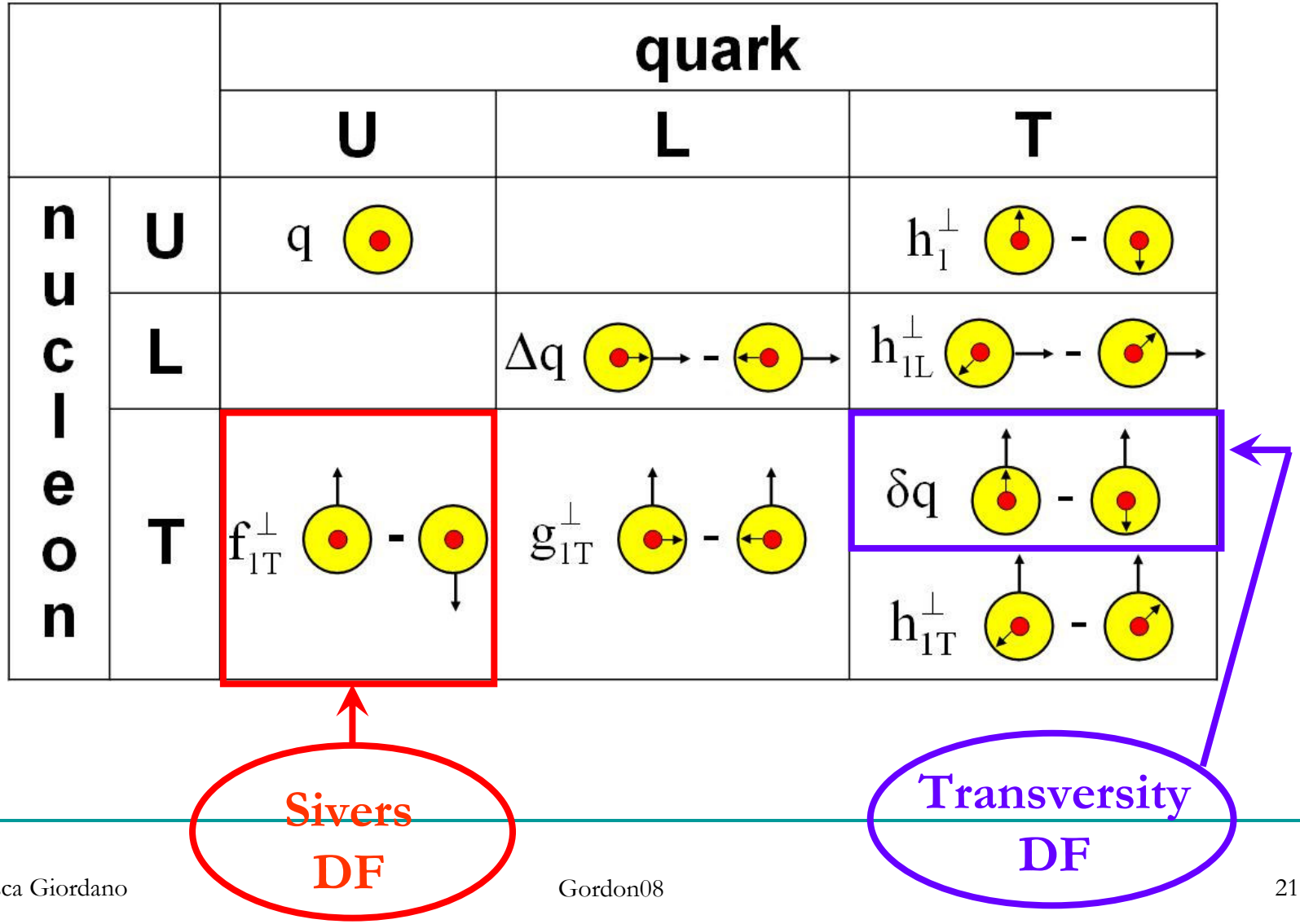
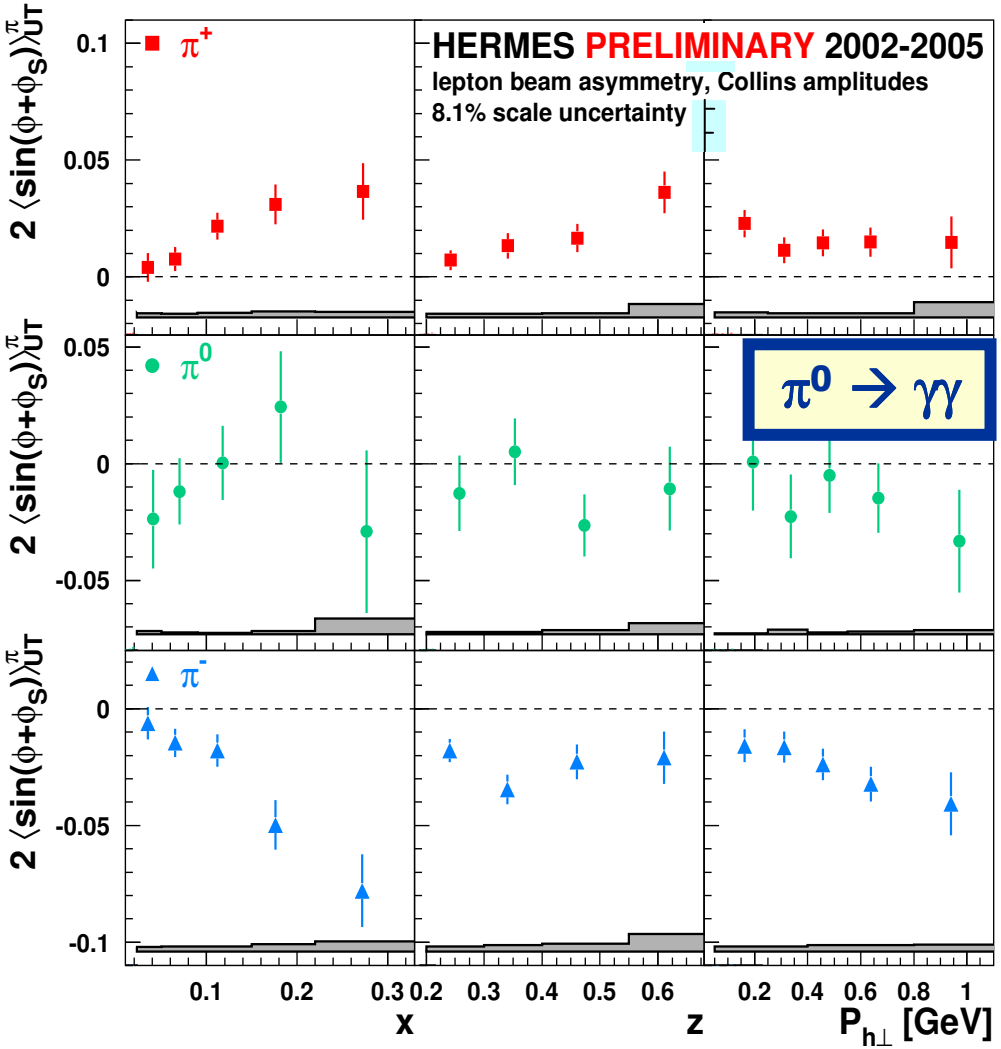


Sivers mechanism

The Sivers function $f_{1T}^{\perp q}(x, p_T^2)$ describes the correlation between the transverse polarization of the nucleon and the transverse momentum of the struck quark → **spin-orbit structure** of the nucleon

a non-zero Sivers function requires a
non-vanishing orbital angular momentum
inside the nucleon

Collins amplitudes for pions



→ **Large positive for π^+**

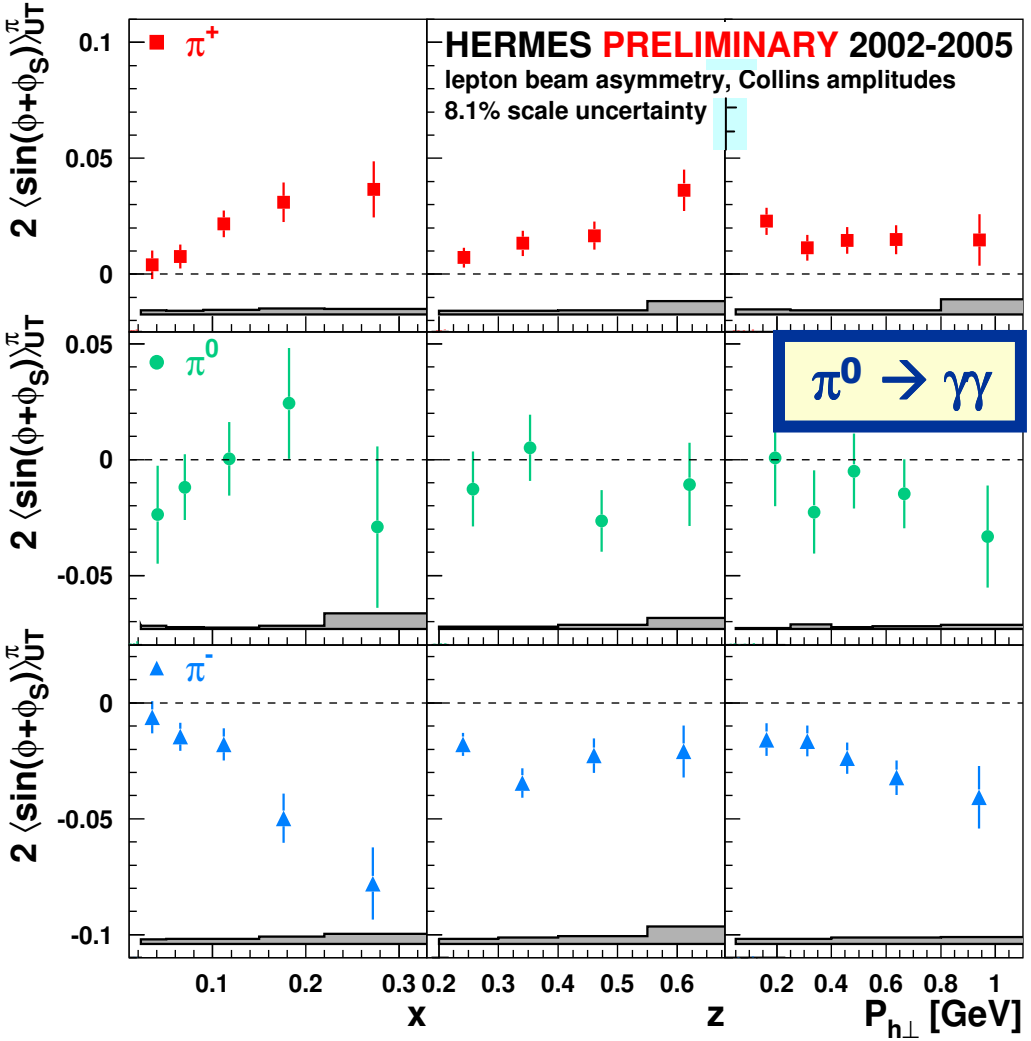
→ **Large negative for π^-**

→ **Consistent with zero for π^0**

$$u \rightarrow \pi^+ \quad H_1^{\perp, fav}$$

$$u \rightarrow \pi^- \quad H_1^{\perp, unfav}$$

Collins amplitudes for pions



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$$H_1^{\perp,unfav} \approx -H_1^{\perp,fav}$$

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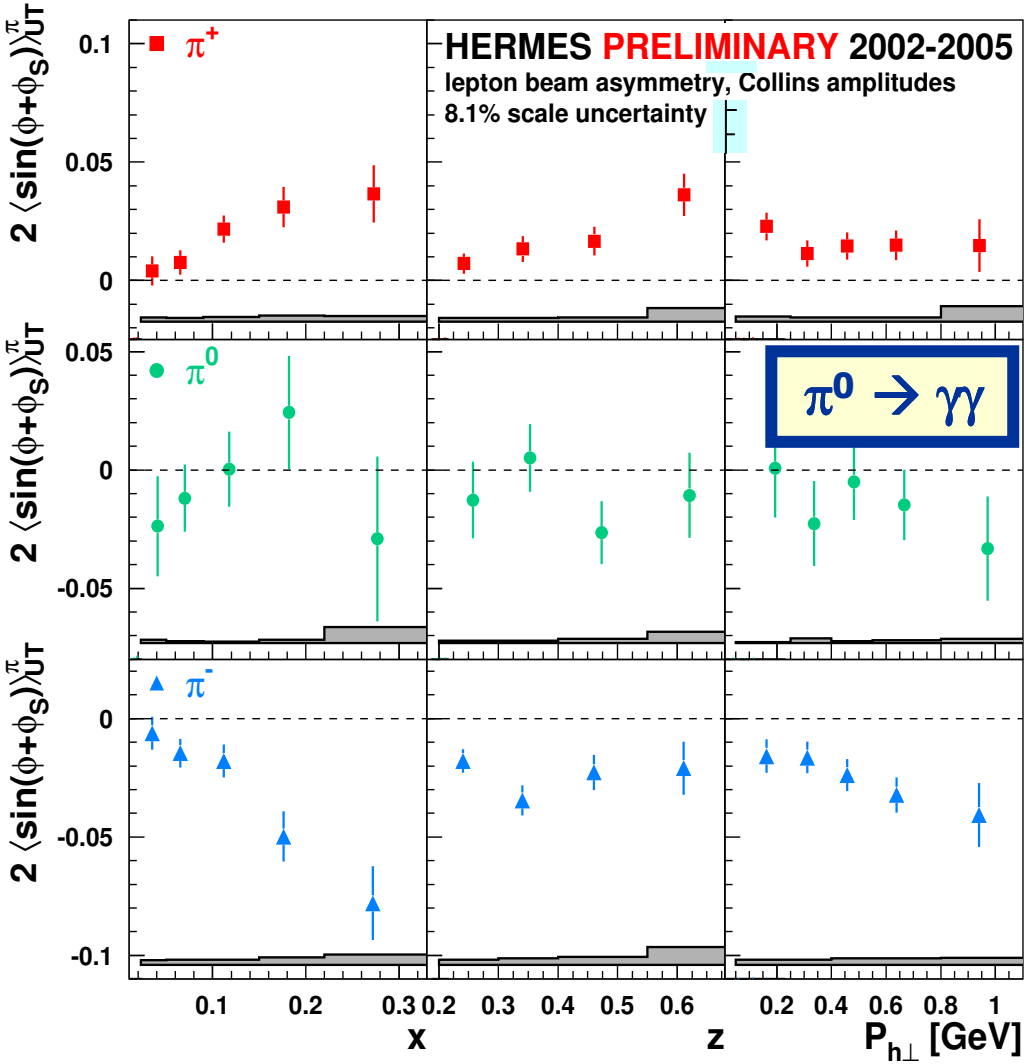

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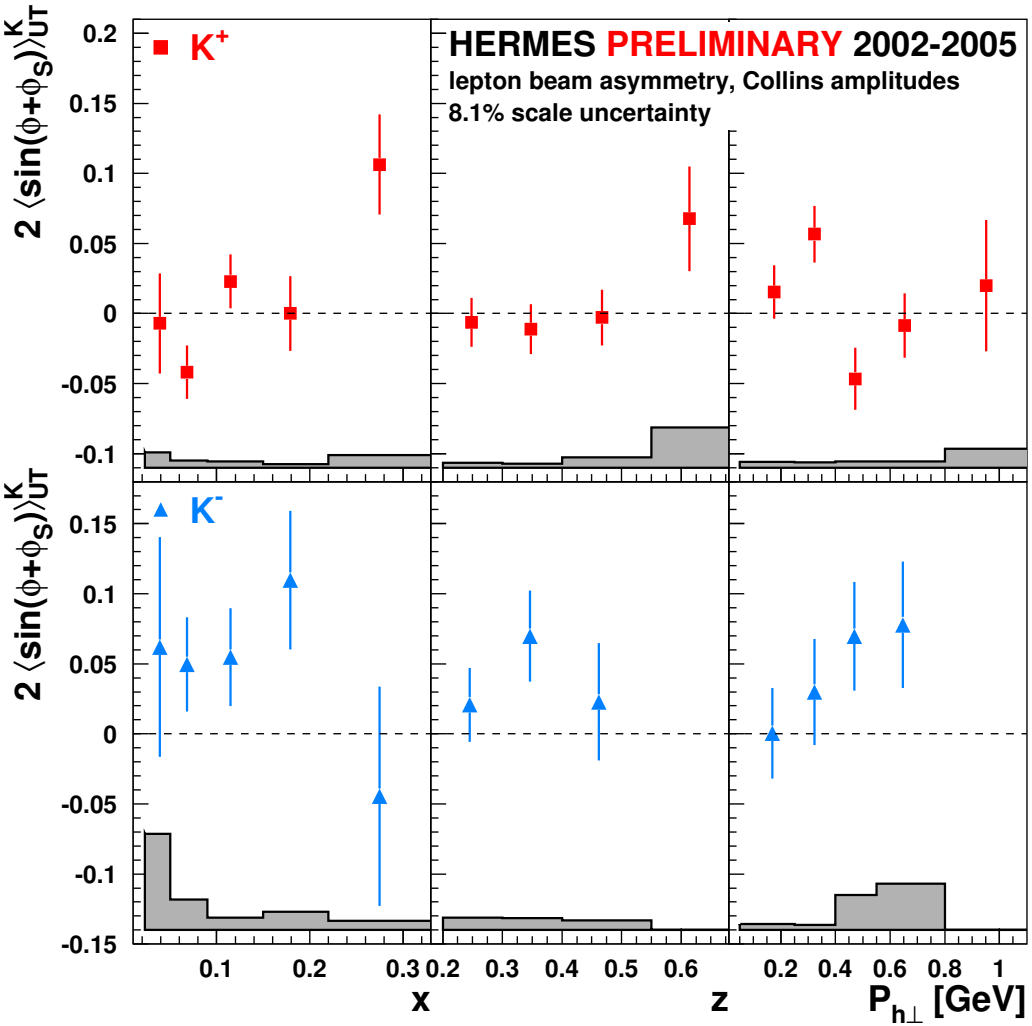
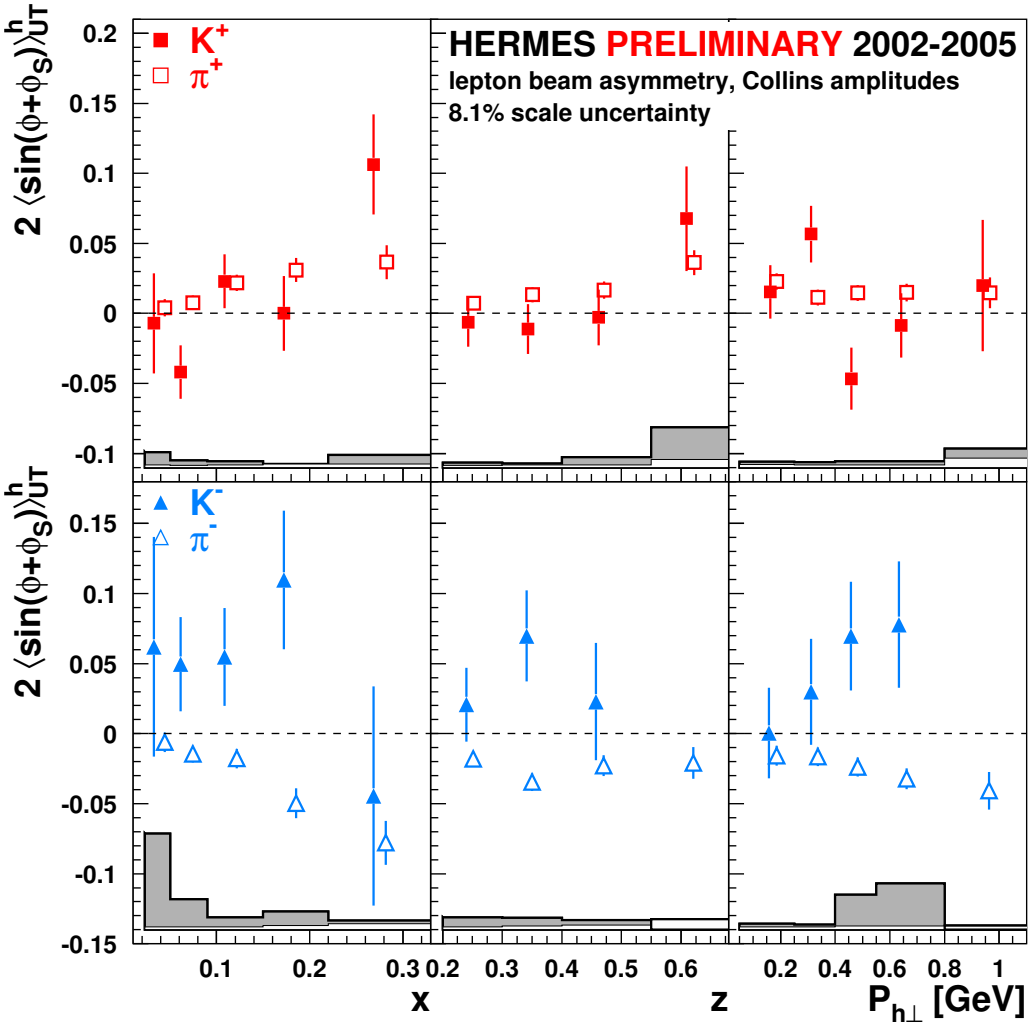
Isospin symmetry fulfilled for π-meson SSA amplitudes!

Collins amplitudes for charged kaons



→ **No significant non-zero Collins amplitudes for Kaons**

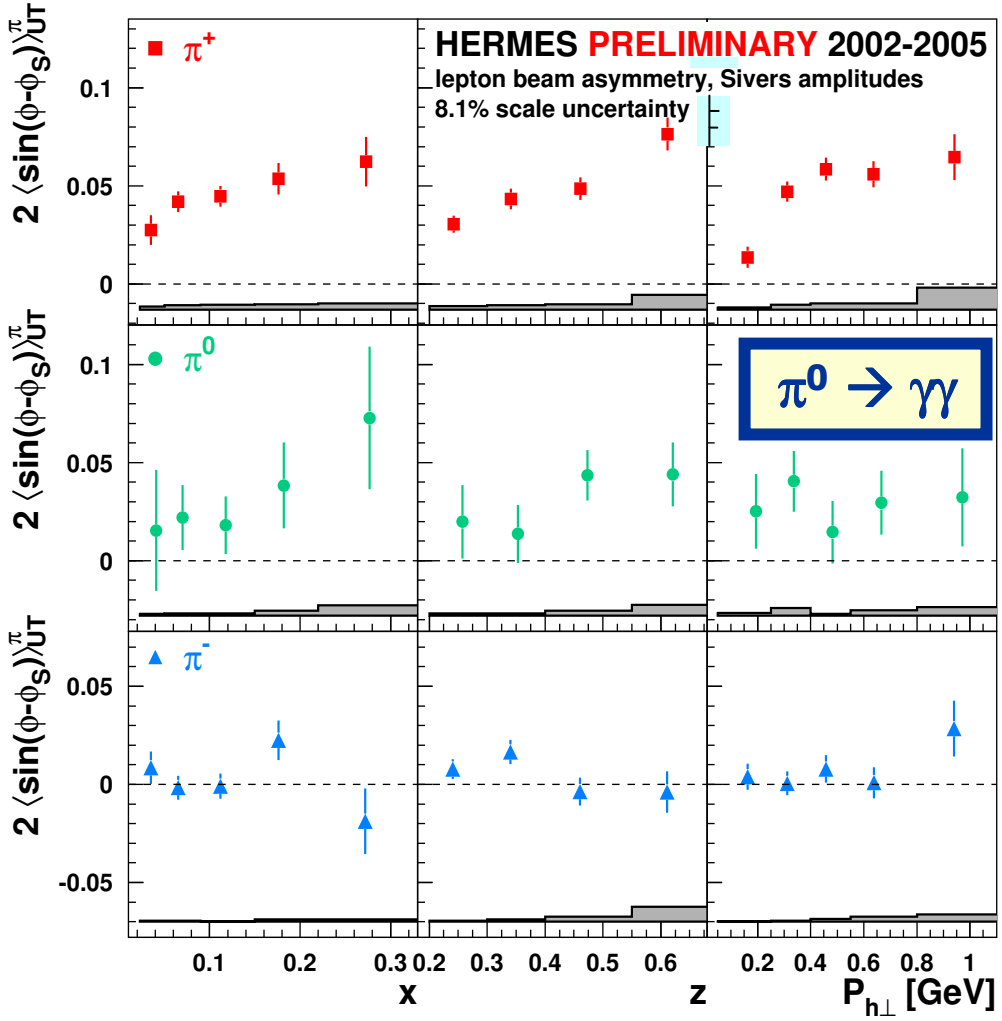
Collins amplitudes for charged kaons



→ **No significant non-zero Collins amplitudes for Kaons**

→ **Collins amplitudes for K^+ compatible with π^+**

Sivers amplitudes for pions



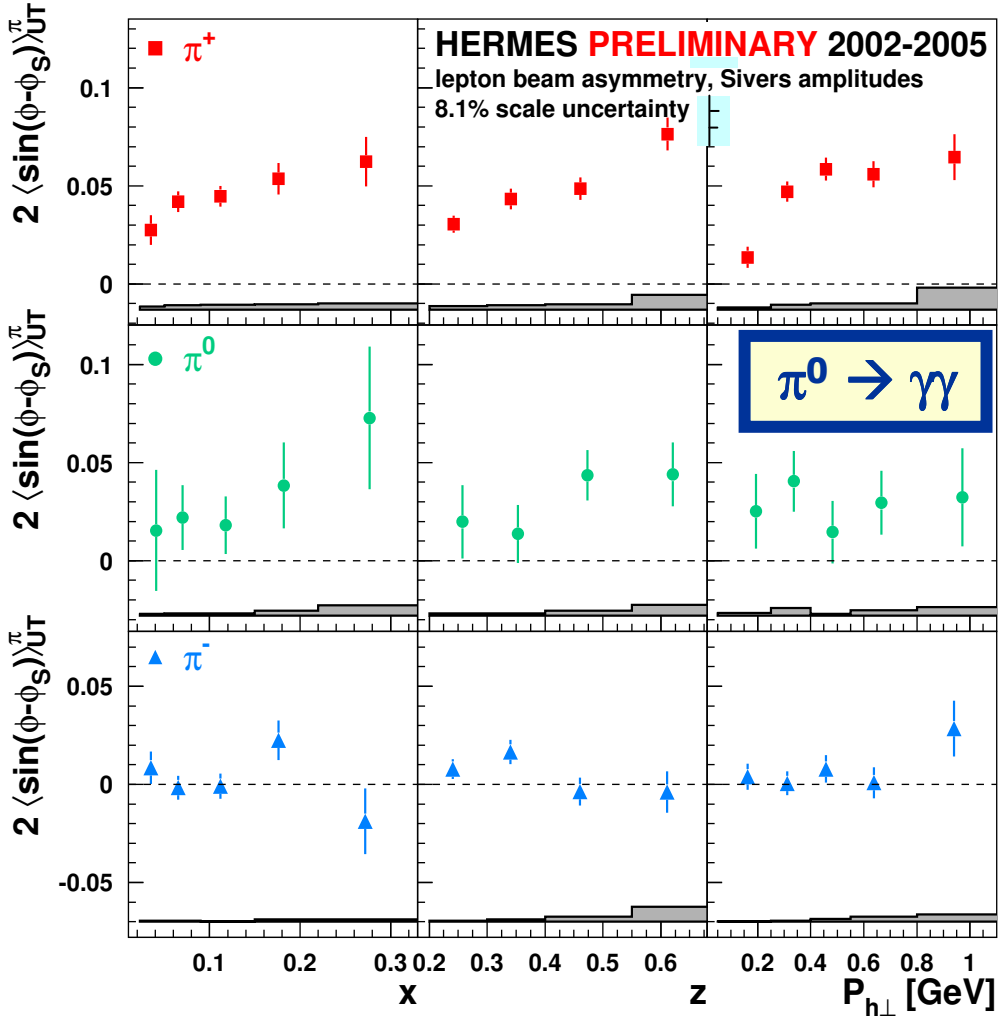
→ Large positive for π^+

→ Consistent with zero for π^-

→ Positive for π^0

Isospin symmetry fulfilled for π-meson SSA amplitudes!

Sivers amplitudes for pions



→ Large positive for π^+

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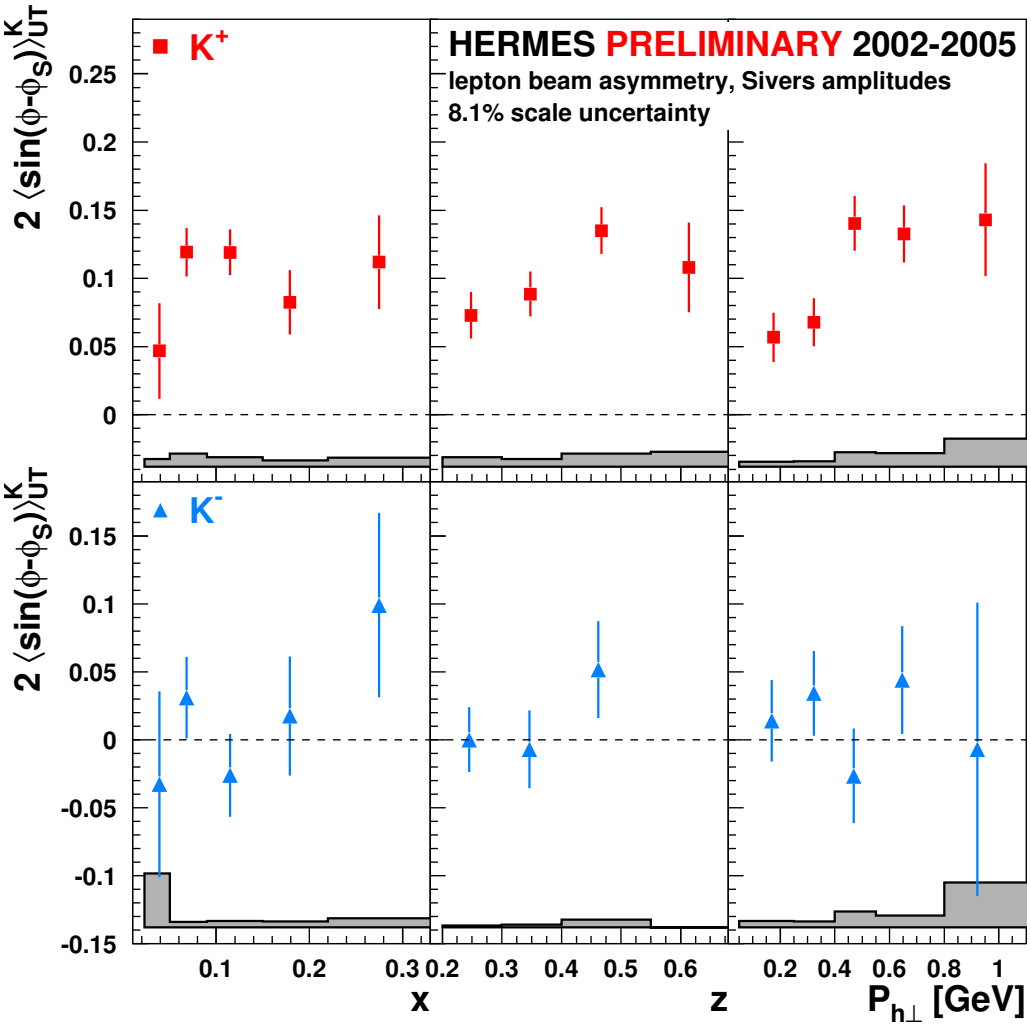
Non zero quark orbital angular momentum !

Isospin symmetry fulfilled for π-meson SSA amplitudes!

Sivers amplitudes for charged kaons



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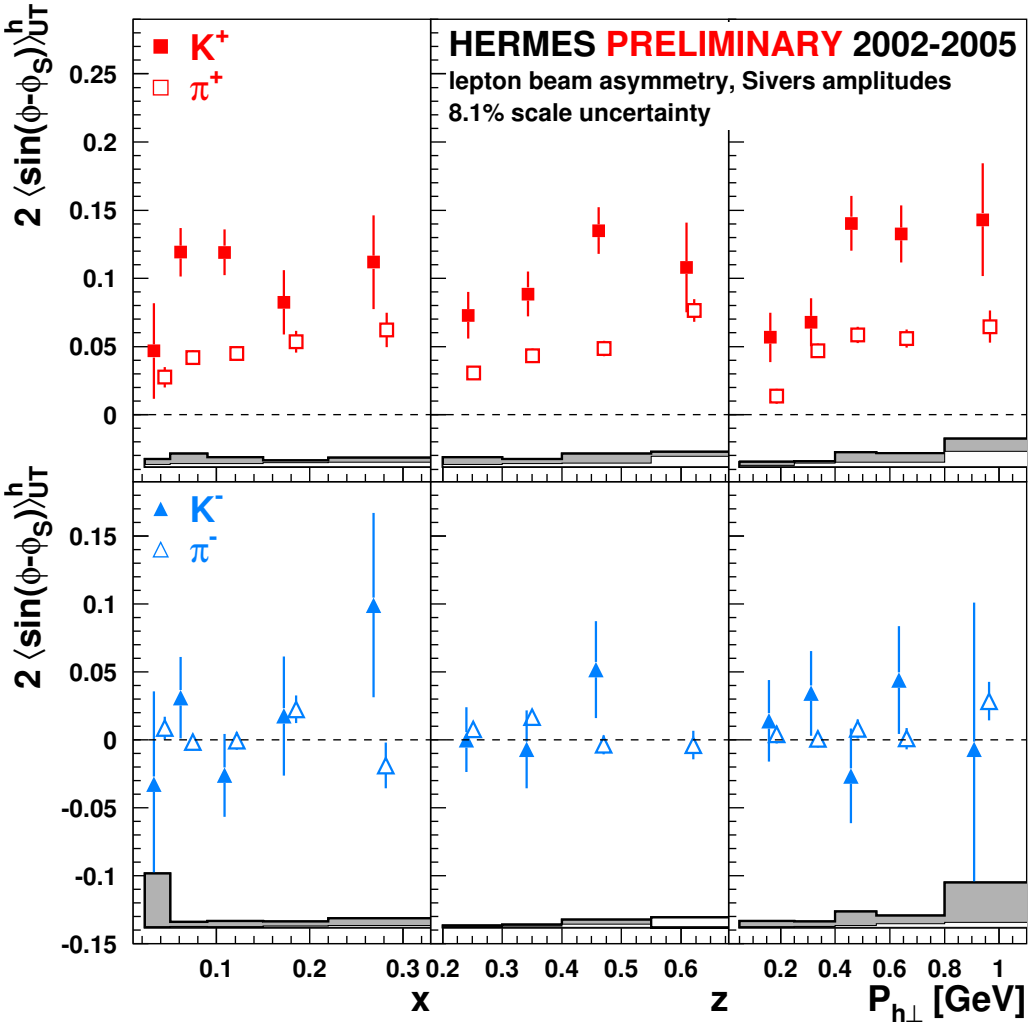

→ **Large positive for K^+**

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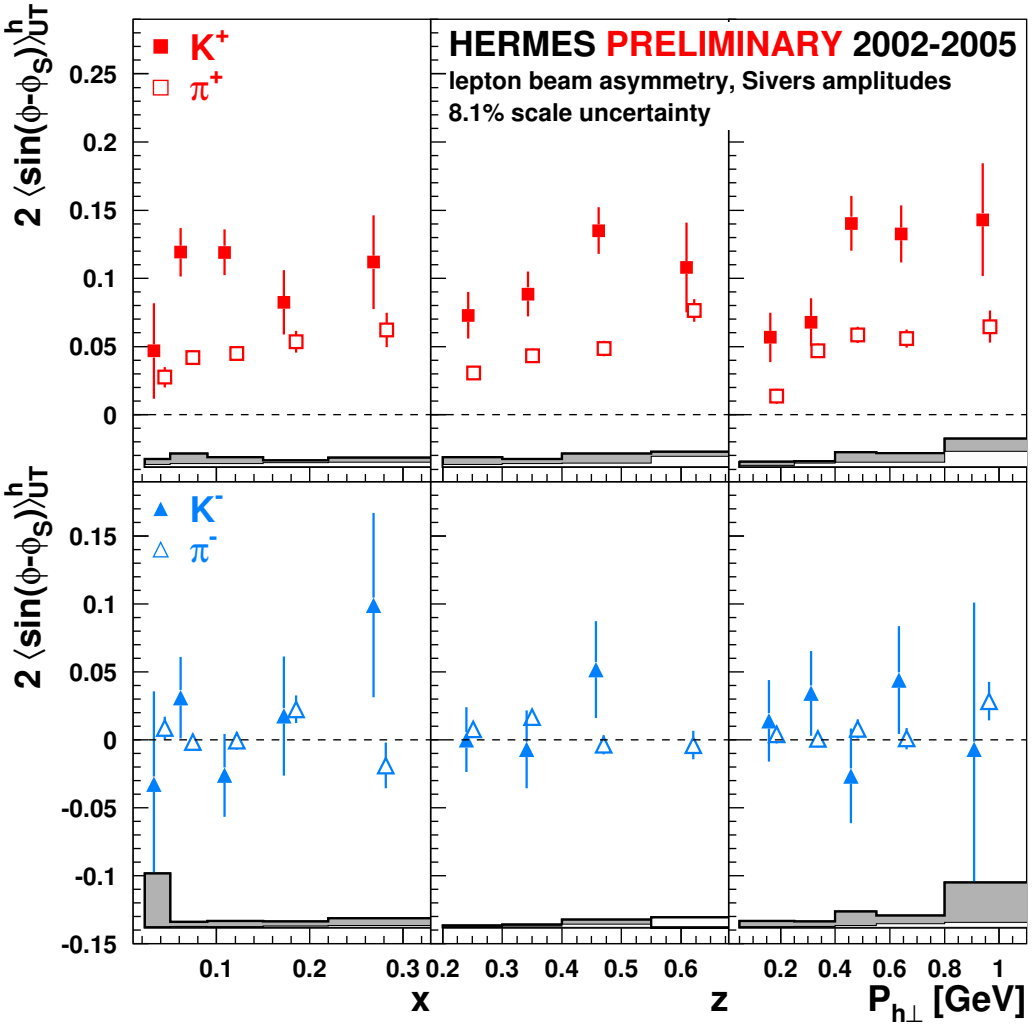
→ **K^+ amplitudes are larger than the π^+ amplitudes!**

Sivers amplitudes for charged kaons



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→ **K^+ amplitudes are larger than the π^+ amplitudes!**

Suggests a significant sea quark contribution

Semi Inclusive Deep Inelastic Scattering

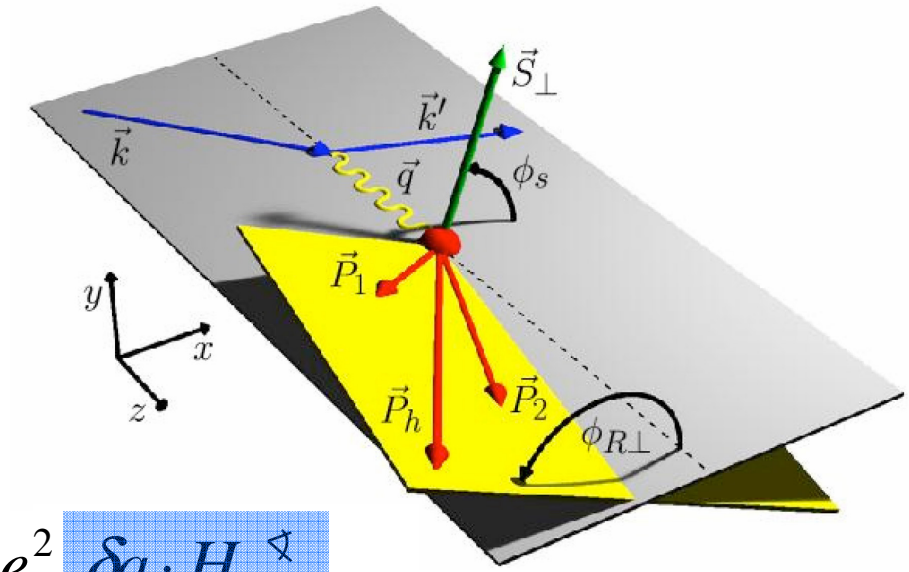
- Independent method to extract δq
- Direct product of transversity and Fragmentation function

(no convolution involved!)

BUT:

- **poorer statistics**
- **increased number of variables**

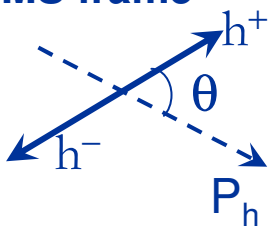
2-hadron production



$$\sigma_{UT} \propto |S_T| \sin\theta \sin(\phi_{R\perp} + \phi_S) \sum_q e_q^2 \, \delta q \cdot H_{1,q}^{\sphericalangle}$$

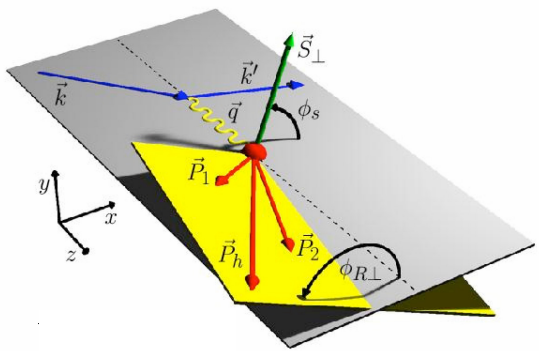
Azimuthal dependence

CMS frame



2-hadron production

$$A_{UT} \equiv \frac{\sigma_{UT}}{\sigma_{UU}} \propto \left|S_T\right| \sin(\phi_{R\perp} + \phi_S)$$



$$\frac{\sin\theta \sum_q e_q^2 \delta q(x)\left[\ H_{1,q}^{\sphericalangle,sp}(z, M_{\pi\pi}^2) + \cos\theta\ H_{1,q}^{\sphericalangle,pp}(z, M_{\pi\pi}^2)\ \right]}{\sum_q e_q^2 q(x)\left[\ D_{1,q}(z, M_{\pi\pi}) + \cos\theta\ D_{1,q}^{sp}(z, M_{\pi\pi}) + (3\cos^2\theta - 1) D_{1,q}^{pp}(z, M_{\pi\pi})\ \right]}$$

The contribution to the Asymmetry is due to interference of different partial waves of the final state h^+h^-

2-hadron production

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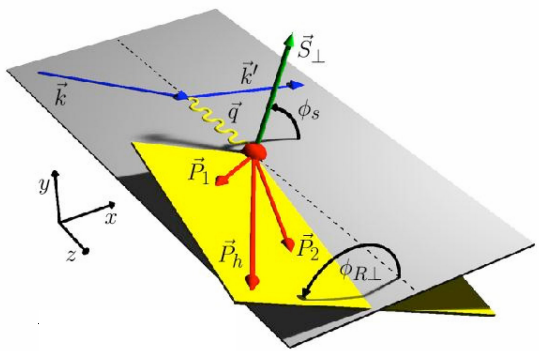
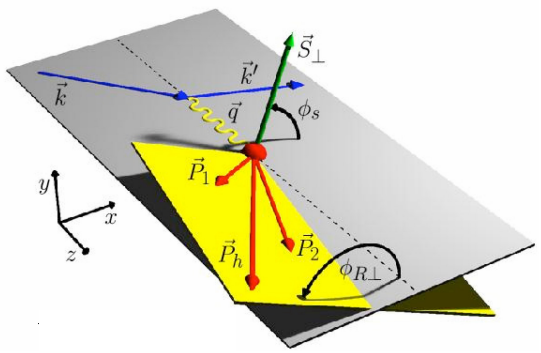


$$\frac{\sin\theta \sum_q e_q^2 \delta q(x)\left[\ H_{1,q}^{\sphericalangle,sp}(z, M_{\pi\pi}^2) + \cos\theta\ H_{1,q}^{\sphericalangle,pp}(z, M_{\pi\pi}^2)\ \right]}{\sum_q e_q^2 q(x)\left[\ D_{1,q}(z, M_{\pi\pi}) + \cos\theta\ D_{1,q}^{sp}(z, M_{\pi\pi}) + (3\cos^2\theta - 1) D_{1,q}^{pp}(z, M_{\pi\pi})\ \right]}$$

$$\theta' \equiv \left\| \theta - \frac{\pi}{2} \right| - \frac{\pi}{2} \Bigg|$$

2-hadron production

$$A_{UT} \equiv \frac{\sigma_{UT}}{\sigma_{UU}} \propto \left|S_T\right| \sin(\phi_{R\perp} + \phi_S)$$



$$\frac{\sin\theta \sum_q e_q^2 \delta q(x)\left[\ H_{1,q}^{\sphericalangle,sp}(z, M_{\pi\pi}^2) + \cos\theta\ H_{1,q}^{\sphericalangle,pp}(z, M_{\pi\pi}^2)\ \right]}{\sum_q e_q^2 q(x)\left[\ D_{1,q}(z, M_{\pi\pi}) + \cos\theta\ D_{1,q}^{sp}(z, M_{\pi\pi}) + (3\cos^2\theta - 1) D_{1,q}^{pp}(z, M_{\pi\pi})\ \right]}$$

$$\theta' \equiv \left\| \theta - \frac{\pi}{2} \right| - \frac{\pi}{2} \right|$$

The azimuthal moments are extracted from A_{UT} using a 2-dimensional χ^2 fit

$$A_{UT} = \sin(\phi_{R\perp} + \phi_S) \frac{a\ \sin\theta'}{1 + b\ (3\cos^2\theta' - 1)}$$

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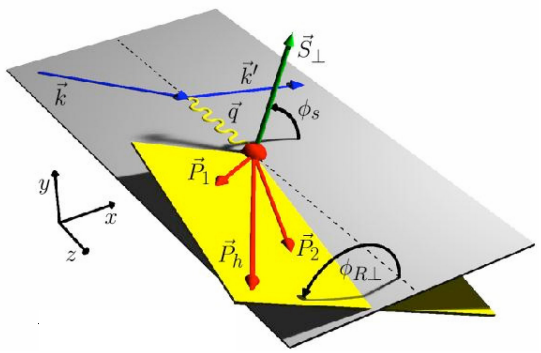


$$\frac{\sin\theta \sum_q e_q^2 \delta q(x) \left[H_{1,q}^{\sphericalangle,sp}(z, M_{\pi\pi}^2) + \cos\theta \, H_{1,q}^{\sphericalangle,pp}(z, M_{\pi\pi}^2) \right]}{\sum_q e_q^2 q(x) \left[D_{1,q}(z, M_{\pi\pi}) + \cos\theta \, D_{1,q}^{sp}(z, M_{\pi\pi}) + (3\cos^2\theta - 1) D_{1,q}^{pp}(z, M_{\pi\pi}) \right]}$$

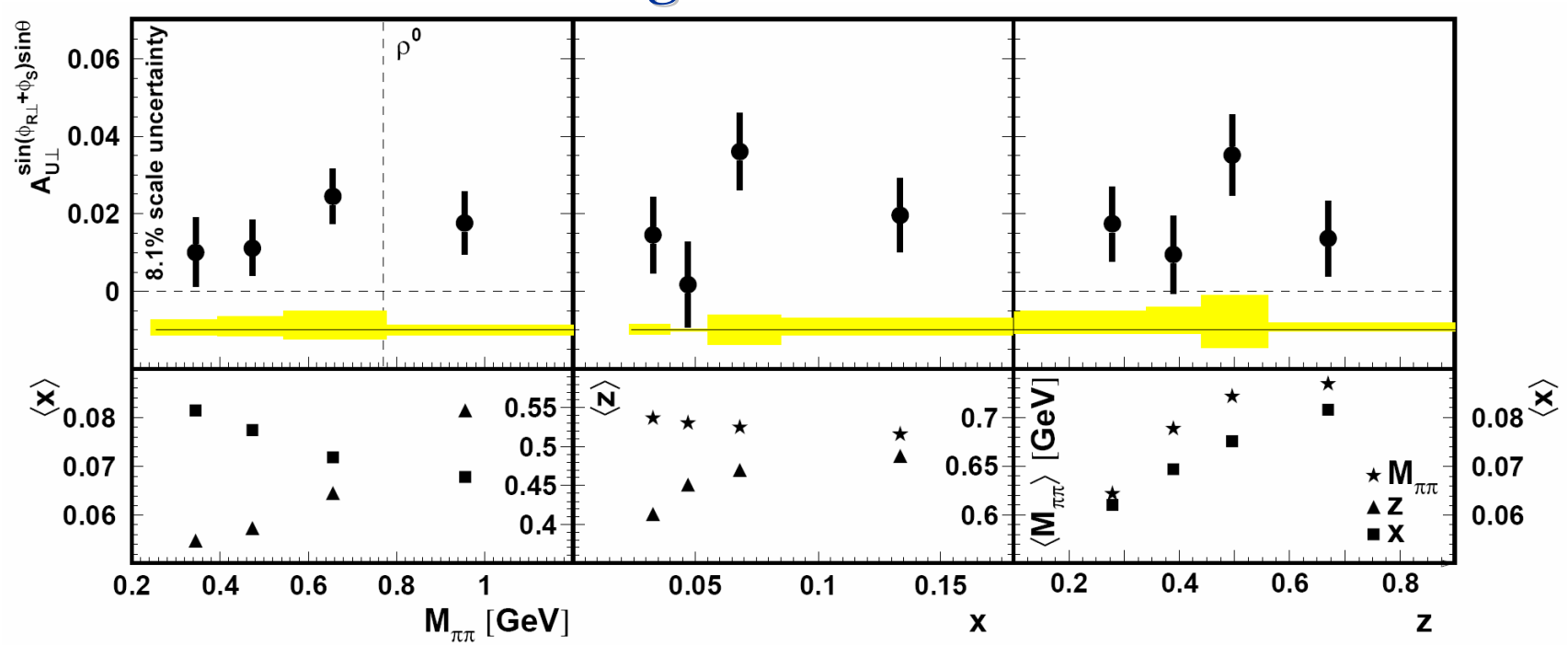
$$\propto \frac{\sum_q e_q^2 \delta q(x) H_{1,q}^{\sphericalangle,sp}(z, M_{\pi\pi}^2)}{\sum_q e_q^2 q(x) D_{1,q}(z, M_{\pi\pi})}$$

$$A_{UT} = \sin(\phi_{R\perp} + \phi_S) \frac{a \sin\theta'}{1 + b\,(3\cos^2\theta' - 1)}$$

2-hadron production

RICH identification to select pions

First evidence of a T-odd and chiral-odd dihadron fragmentation function!

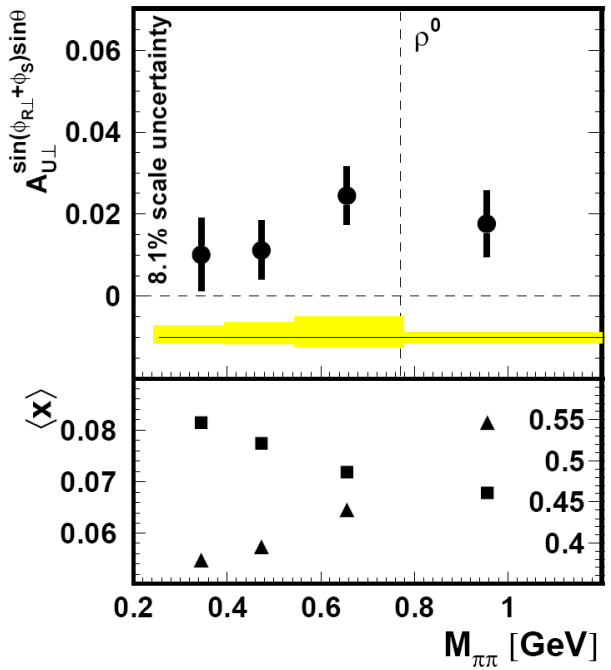


(A. Airapetian et al, JHEP 06 (2008) 017)

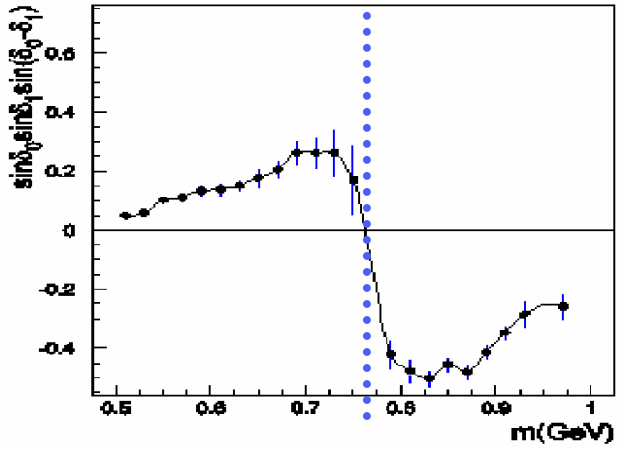
2-hadron production

POSITIVE ASYMMETRY

in the whole range of $M_{\pi\pi}$-mass

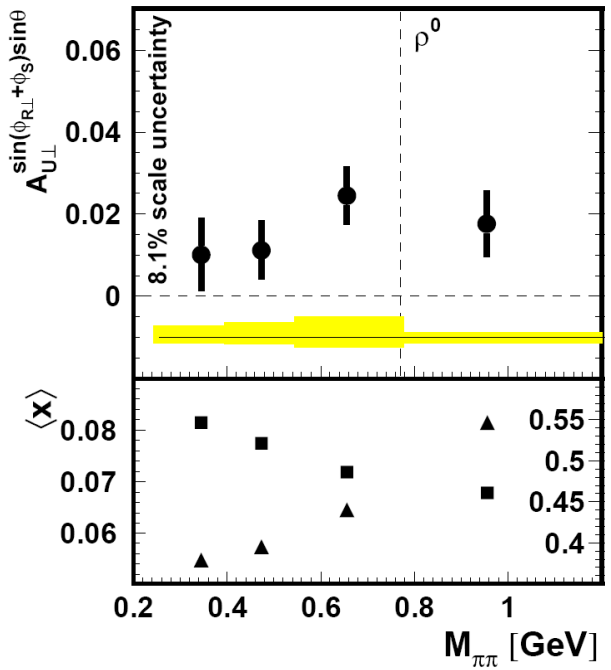


2-hadron production

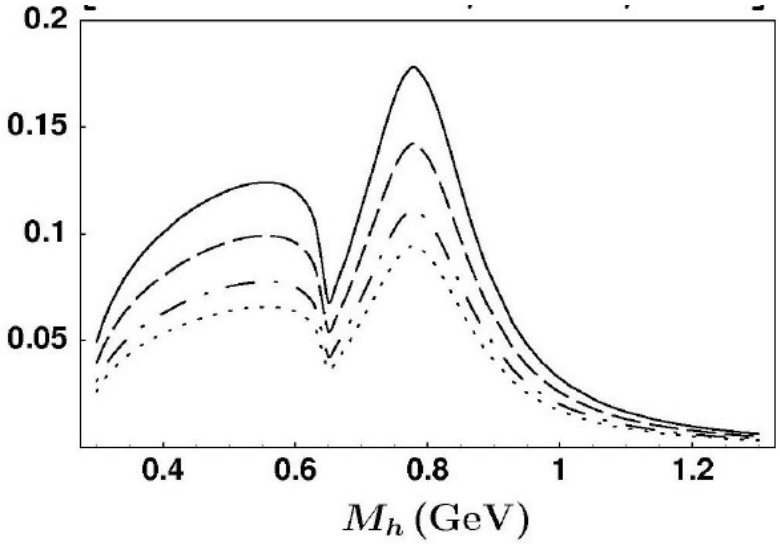


No evidence of the sign-change at the ρ^0 mass predicted by **Jaffe et al**.
(Phys.Rev.Lett.80,(1998))

POSITIVE ASYMMETRY
in the whole range of $M_{\pi\pi}$-mass



2-hadron production



Prediction by Bacchetta & Radici consistent with mass dependence
(Phys.Rev.D 74,(2006))

POSITIVE ASYMMETRY
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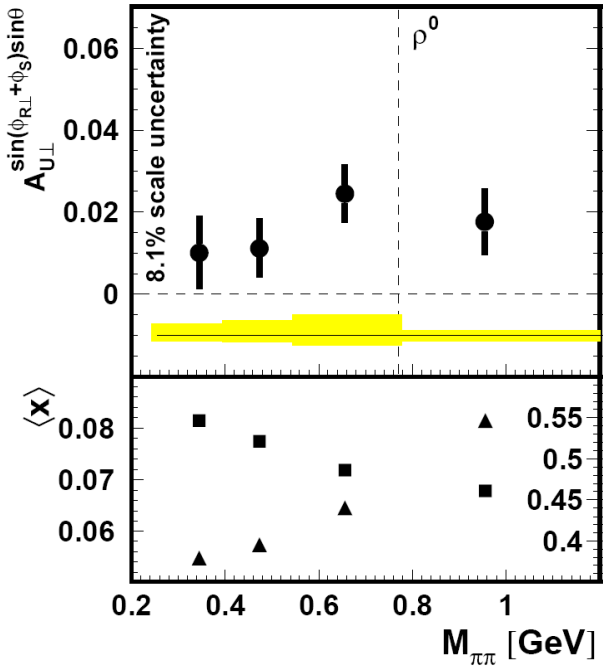
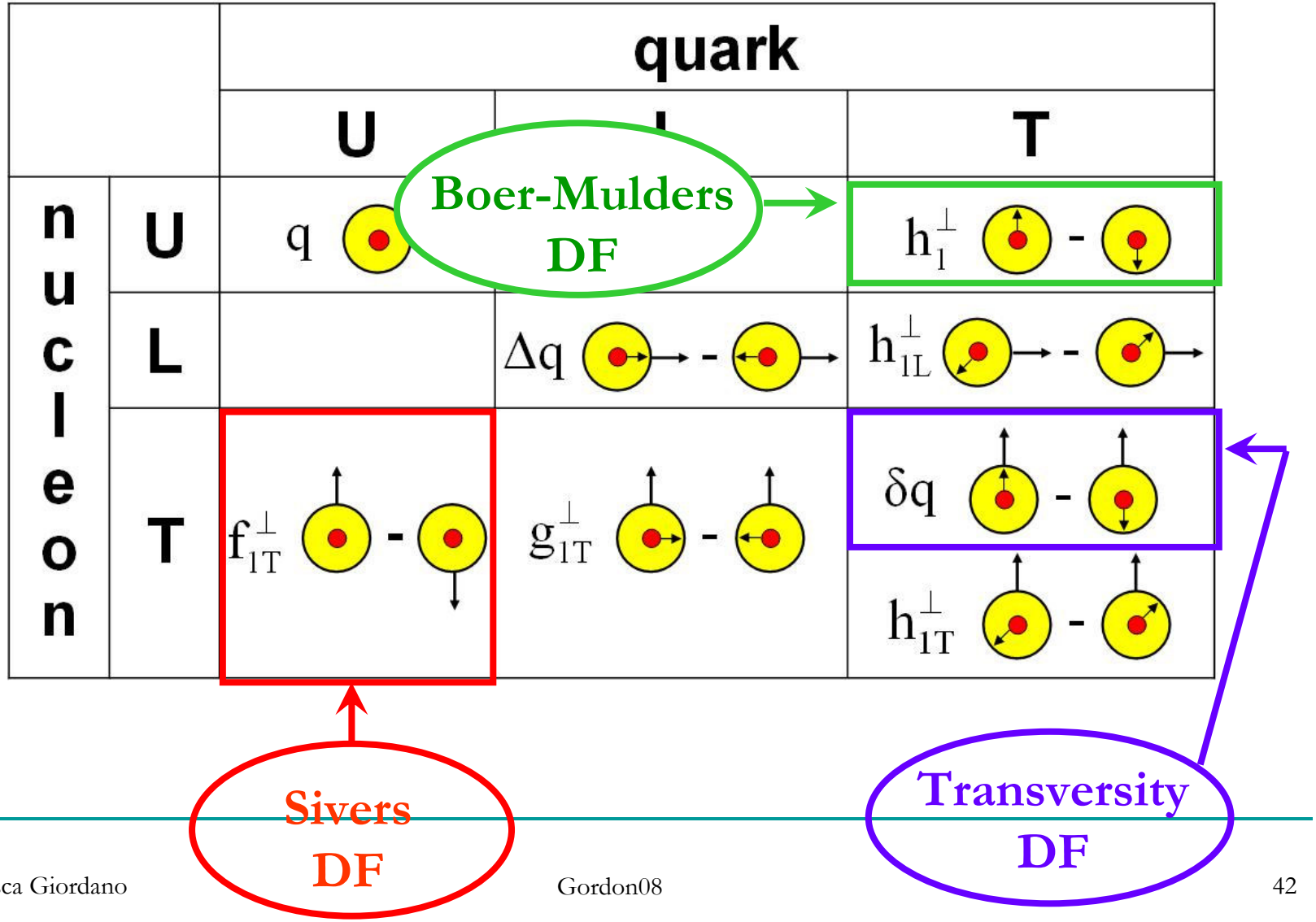
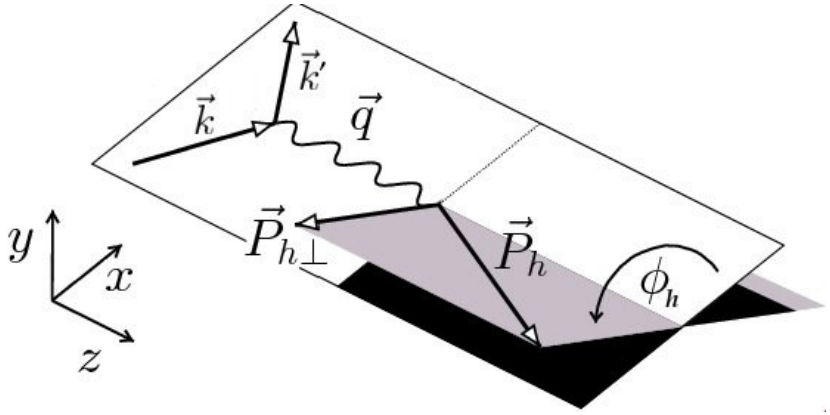


The TMD Distribution Functions



Unpolarized Semi Inclusive Deep Inelastic Scattering



$$\frac{d^5\sigma}{dx\ dy\ dz\ d\phi\ dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2}\left(1+\frac{\gamma^2}{2x}\right)\Big\{A(y)\ \ F_{UU,T} + B(y)\ \ F_{UU,L}$$

$$+C(y)\ \ \cos\phi\ F_{UU}^{\cos\phi} + B(y)\ \ \cos 2\phi\ F_{UU}^{\cos 2\phi}\Big\}$$

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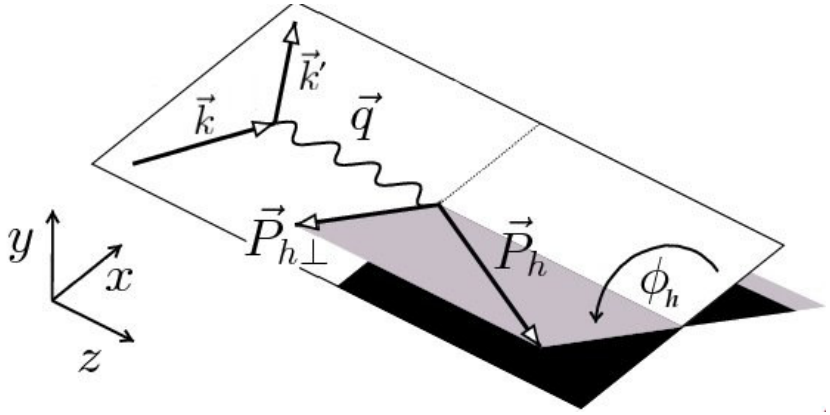

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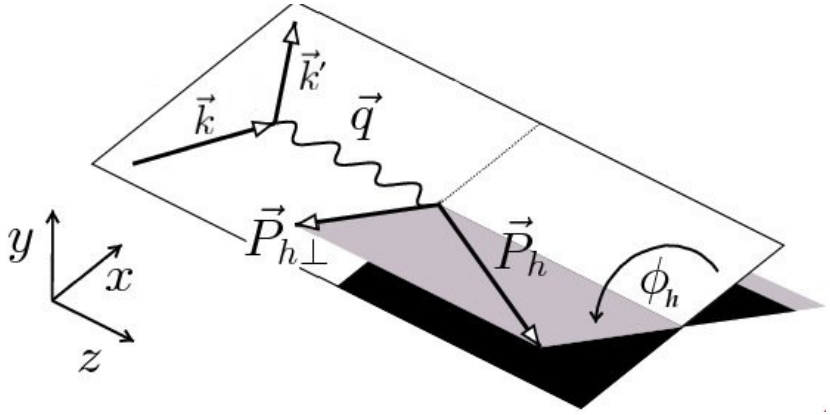

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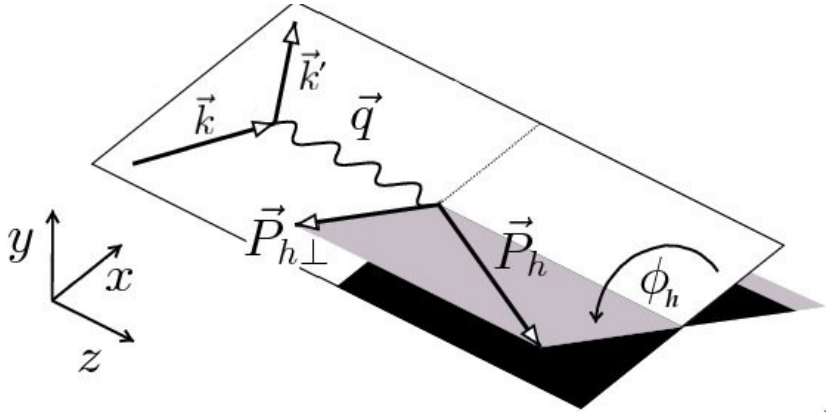

Multi-dimensional unfolding procedure in progress!

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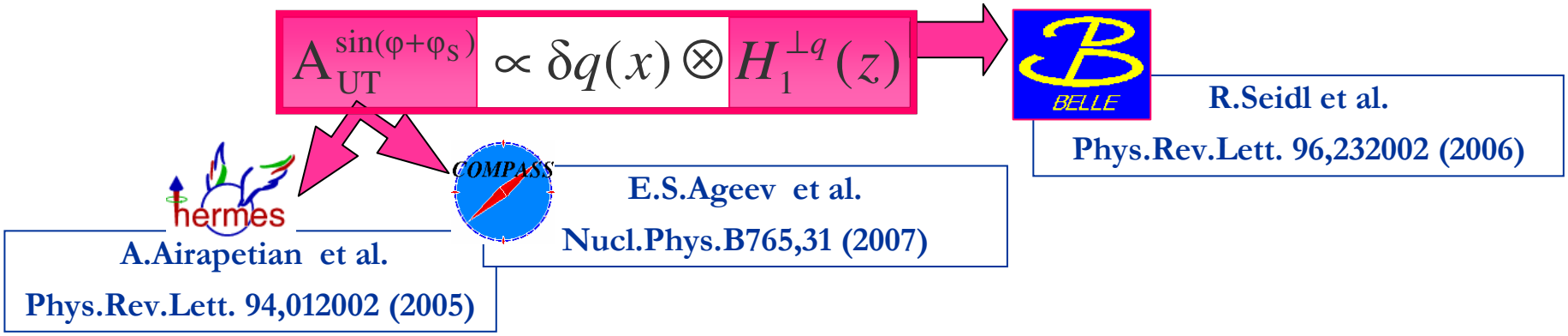
Conclusion

1-hadron production:

- First evidence of a significant SSA Collins amplitudes for π-mesons

  ➡ allowed the first extraction of the transversity function!

  (Anselmino et al. Phys.Rev. D75(2007))



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Thank you!

Vector meson contamination